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TTCS Condenser Freezing Test Plan

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Summary

For the AMS experiment onboard the International Space Station a thermal control system, known as the Tracker Thermal Control System (TTCS) is being developed. The TTCS basically consists of a mechanically pumped two-phase loop, where heat is collected at two evaporators and rejected at two radiators. The loop contains carbon dioxide. Critical parts of the loop are protected against freezing, using thermostats and heaters. However, during (accidental) total power down of the experiment, some parts may freeze.

This document describes a test plan and procedure to determine the TTCS condenser maximum design pressure. A stress calculation approach is presented as a starting point for the condenser design. Furthermore an overall activity sequence table is given which describes steps to be taken for the condenser to be space qualified.

Document Change Log

Issue	Description	Page no.	Date	By
1.0	First issue	-	Nov 2004	G. van Donk
2.0	Stress calculations added		Feb 2005	G. van Donk/R. van Houten
2.1	- Stress equations corrected (calculations were OK, but some copy/paste errors are now corrected) - Stress calculation results presented in tables - Epoxy data sheet added (appendix A)	18 19 28,29	Aug 2005	G. van Donk/R. van Houten

(29 pages in total)

1 Introduction

1.1 General

During (accidental) AMS experiment power down the TTCS condenser and part of it's feed and return lines may freeze. If no measures are taken the condenser eventually may burst during thawing. To avoid this a condenser is being designed comprising a number of capillary tubes in parallel, attached to an interface plate which in turn is bolted to the radiator heat pipes.

1.2 Test objective

The test objective is to determine the condenser maximum design pressure. This pressure will occur during heat-up and thawing of the condenser after being cooled down.

2 Condenser design approach

Design approach is to construct the condenser such that it can withstand the pressure which occurs, during heat-up, due to thermal expansion of carbon dioxide. Carbon dioxide solid to liquid transition has a free expansion of 28.5%. Small diameter tubing is chosen, with an inner diameter of approximately 1.0 mm, to handle very high pressures (up to a few thousand bar).

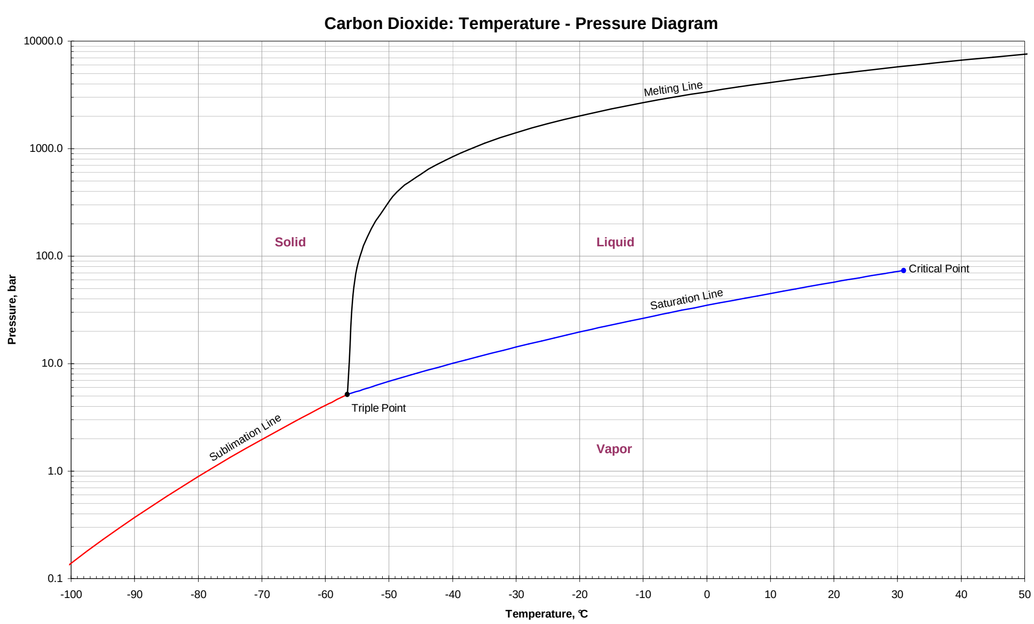


Figure 2-1: Carbon dioxide T-p diagram

As it is uncertain how trapped CO_2 will behave during thawing it is proposed to determine the condenser maximum design pressure by test. One of the theories is that, during thawing, the trapped CO_2 will follow the melting line as shown in *Figure 2-1*. In that case the pressure may rise up to 3000 bar when the condenser temperature is –5 °C, while the feed and return lines are still blocked by solid CO_2 (at 5 bar, the CO_2 freezing point is –56 °C).
In this specific case the trapped CO_2 will be (partly) solid at –5 °C. Current maximum, AMS non operational (e.g. the situation after freezing), radiator temperatures are calculated to be –5 °C.

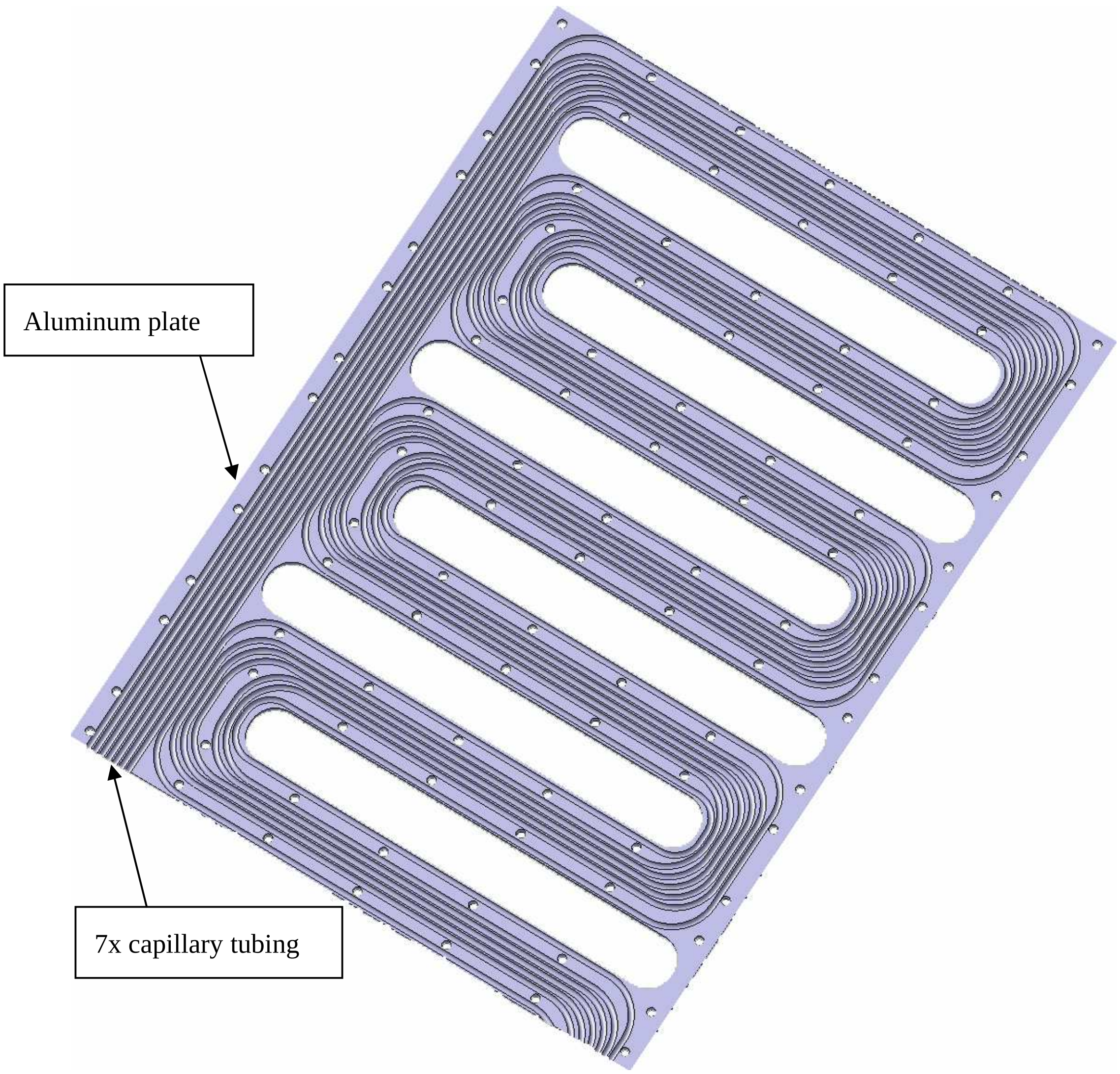


Figure 2-2: Preliminary condenser design, capillary tubing in parallel

3 Freezing philosophy

The expected freezing and thawing sequence is shown schematically in *Figure 3-1* and *Figure 3-2* and described in detail in *Table 3-1*.

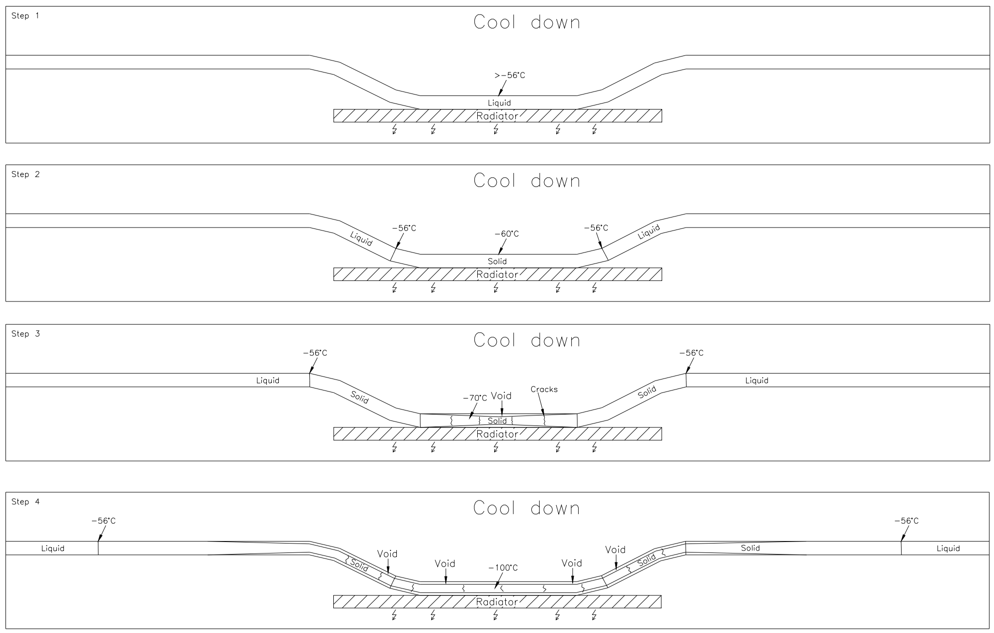


Figure 3-1: Condenser cool down sequence

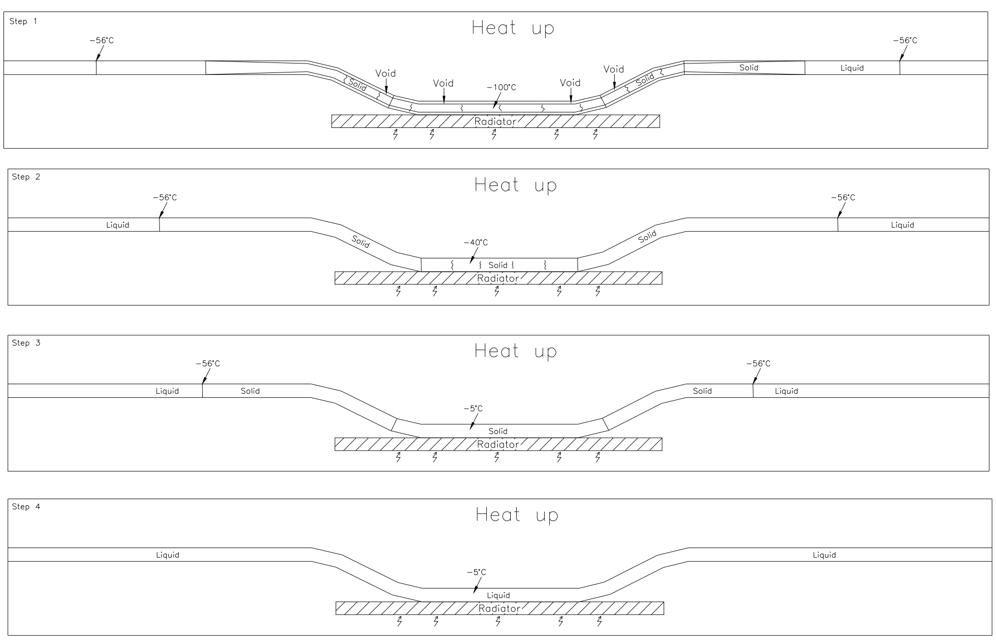


Figure 3-2: Condenser heat up sequence

Step #	COOL DOWN SEQUENCE
1.	Initial state: radiator, condenser and feed & return lines are well above freezing point (>-56 °C)
2.	Radiator temperature falls below freezing point (< -56 °C), feed & return line start to freeze
3.	Freezing front moves along feed & return lines, away from the condenser, meanwhile blocking liquid that otherwise would possibly enter the voids in the condenser. As the tube diameter is very small (only 1 mm) liquid blocking is considered to be close the freezing front.
4.	Radiator temperatures decreases and freezing front moves further away from the condenser.
Step #	**HEAT UP SEQUENCE**
1.	Initial state: radiator, condenser and part of feed & return lines are frozen (<-56 °C)
2.	Condenser exits are blocked, condenser is above –56 °C, pressure increases. CO_2 is still still (partly) frozen, because of high pressure
3.	Temperature and pressure keep rising, condenser exits are still blocked. CO_2 is still frozen.
4.	When feed & return lines thawing finally frees up the condenser exits, pressure rapidly decreases, causing the condenser content to melt.

Table 3-1: Condenser cool down and heat up sequence

4 Sequence of (test) activities

A number of activities are proposed which eventually leads to a space qualified condenser for the AMS project. This document however focuses on steps 1 through 2.1.

Step	Activity
1	**Determination of condenser Maximum Design Pressure (MDP)**
1.1	Design and build test set-up, using strain gauges
1.2	Perform representative freezing tests using above test set-up
1.3	From test results derive condenser MDP
2	**Make a condenser design (iteration procedure of points here below)**
2.1	Perform stress calculations, using condenser MDP and appropriate safety factors
2.2	Optimise tube routing (from thermal, hydraulic and stress point of view)
2.3	Determine/calculate influence of thermal expansion
3	**Condenser engineering/qualification model manufacturing**
3.1	Determine brazing, solder and heat treatment sequence
3.2	Remember that there is a large difference between manifold MDP (160 bar) and condenser MDP (TBD bar). An acceptable sequence of assembly/manufacturing and required (pressure) tests should be determined.
4	**Maximum design pressure verification**
4.1	Verify by CO2 freezing test (very high pressures probably not possible to apply using standard methods)

Table 4-1: Sequence of activities

5 Test set-up

5.1 Test philosophy and starting-points

It is assumed and in some cases calculated that, in orbit, freezing problems occur under the following circumstances:

- The AMS experiment with all equipment inside never falls below –56 °C
- Freezing starts at the condensers
- Thawing starts at the condensers
- The maximum non-powered cool-down radiator temperature rate-of-change is 0.8 °C/min
- The maximum non-powered heat-up radiator temperature rate-of-change is 1.7 °C/min

- The maximum, non-operating radiator temperature is –5 °C (TBC)

From the above it follows that:

- The accumulator temperature is always higher than the frozen part of the loop
- The system is pressurised: T_{accu} determines $p_{sat}=p_{overall\_system}$
- Prior to freezing the condenser and feed & return lines are completely filled with CO_2-liquid
- Most part of feed & return lines environment temperature > CO_2 freezing point
- Feed & return lines will partly freeze, starting from the condensers
- Feed & return lines thawing starts from the condensers

5.2 Test set-up to determine the condenser maximum design pressure

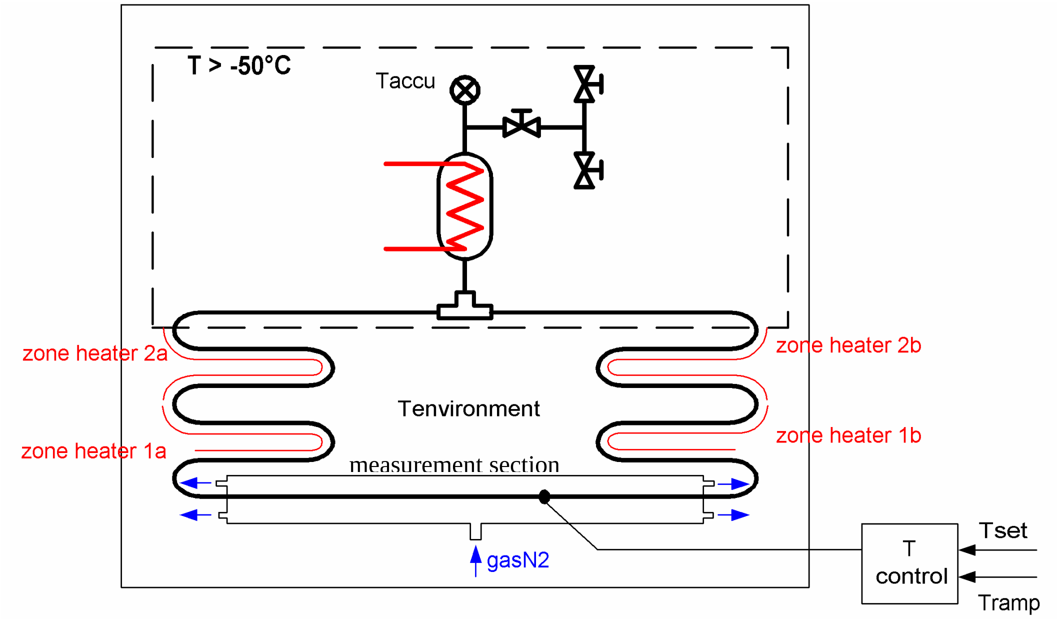


Figure 5-1: Test set-up schematic

A downscaled CO2-loop will be built and tested in an environment well below the freezing point of CO2, see Figure 5-1. This loop will be equipped with a temperature controlled accumulator and a capillary tube, partly equipped with strain gauges. This part will be referred to as the 'measurement section' and is temperature controlled independently from the other components. The number of couplings, branches and intrusive test components will be minimised to avoid accidental leak. The loop will be evacuated and filled with CO2. While being pressurised, by controlling the accumulator temperature, the condenser will be cooled below the freezing point of CO2. The feed and return lines will be cooled below the CO_2 freezing point as well, starting from the condenser side. For this purpose the feed & return lines are equipped with zone heaters which will be switched off one after another to create a 'propagating freezing front'. After a dwell time of several hours the measurement section will be temperature controlled to a temperature above the freezing point, while watching and recording the strain gauge outputs. As long as the measurement section tube is elastic, the temperature will be increased and the strain gauge outputs recorded. The complete cycle will be repeated twice to get more information on reproducibility.

Subsequent steps depend on the test results:

a) Test results do reproduce

- Increase the measurement section temperature up to +25 °C or until the section bursts, whichever comes first.

b) Test results can not be reproduced

- Stop the test by changing all temperatures to +25 °C in the required sequence.
- Calibrate the measurement section again
- Compare calibration after the test to calibration before the test

In the past similar tests have been performed on another condenser type, see *Figure 5-2.*

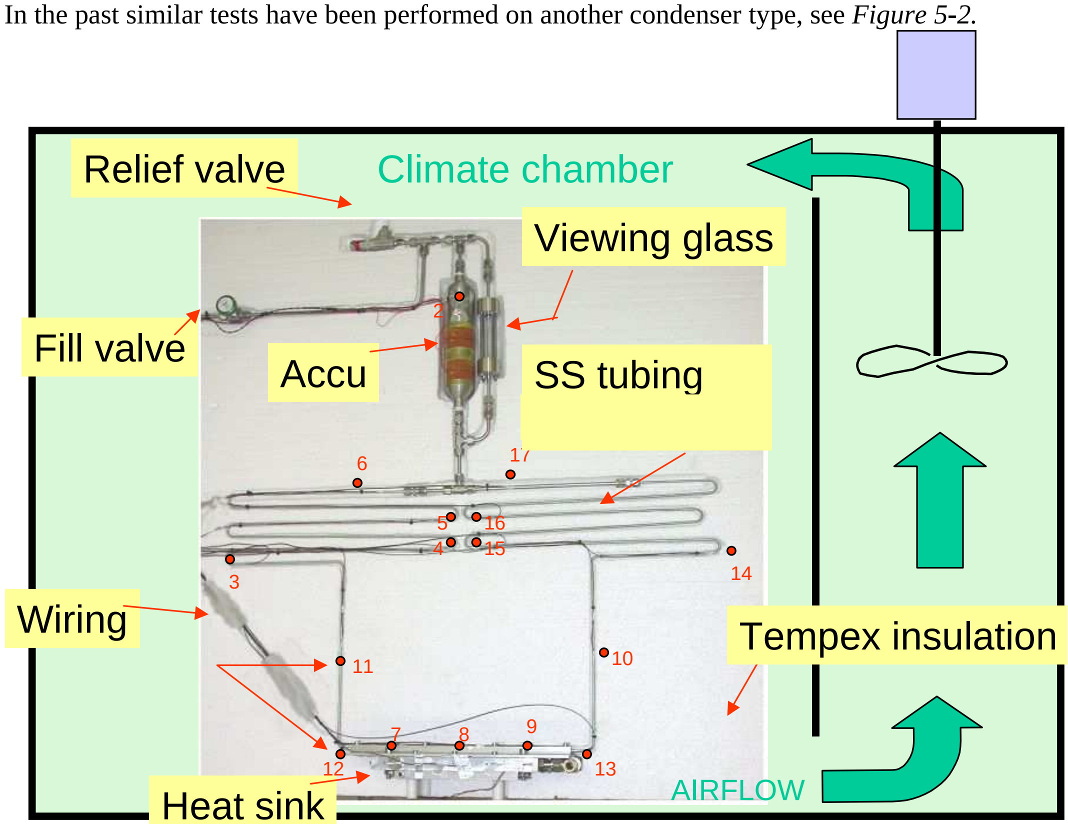


Figure 5-2: Similar Test set-up used for other condenser type testing

5.3 Measurement section details

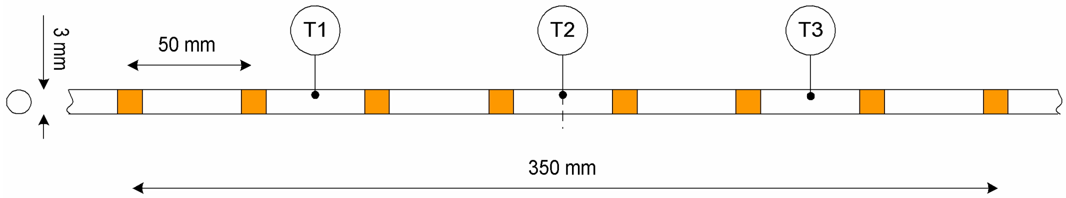


Figure 5-3: Measurement section, here drawn without cooling/heating part

The measurement section consists of a single stainless steel capillary tube, equipped with three thermocouples and eight strain gauges, see *Figure 5-3*. A stronger material, like inconel 718, is preferred for its high strength and therefore high allowed pressure. However inconel 718 delivery time is long and minimum order quantities are large. The tube is part of a simplified CO_2 loop. From a freezing point of view, all parallel capillary tubes are considered independent units which do not interact. Therefore testing only one tube is considered representative for one complete condenser.

Prior to testing the measurement section must be calibrated, preferably at low temperature. An external pressure will be applied and measured while strain gauge outputs are being recorded. This will be repeated three times. A small feasibility test on very small diameter tubing was carried out, see *Figure 5-4*. The results are promising, see *Figure 5-5*

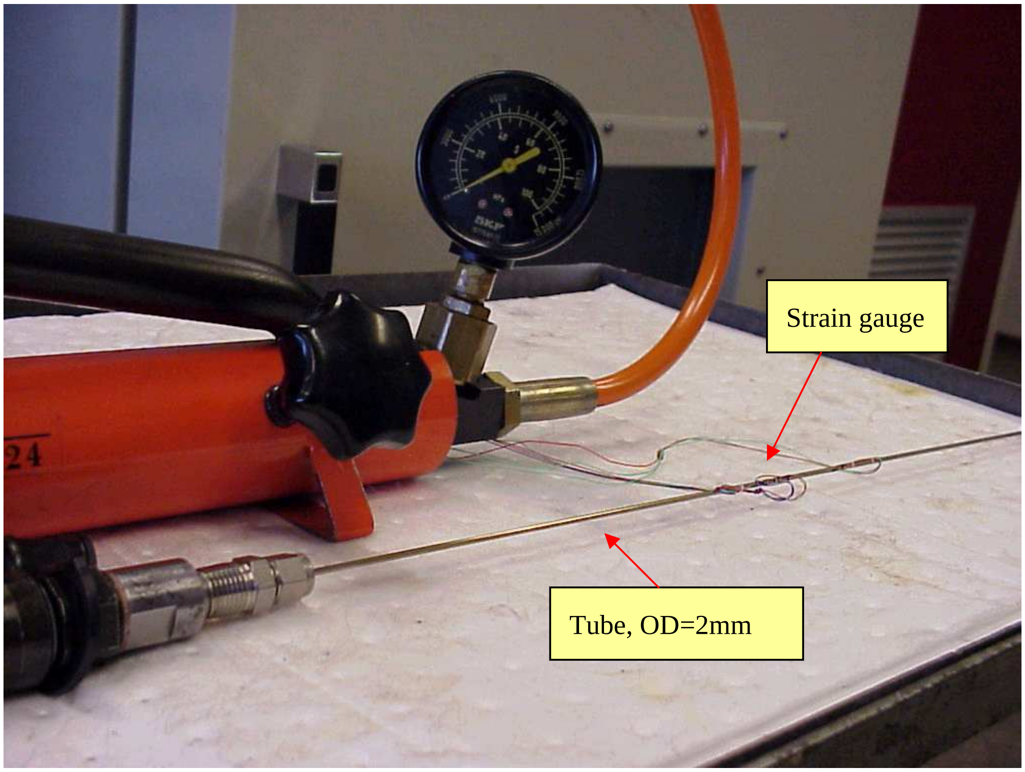
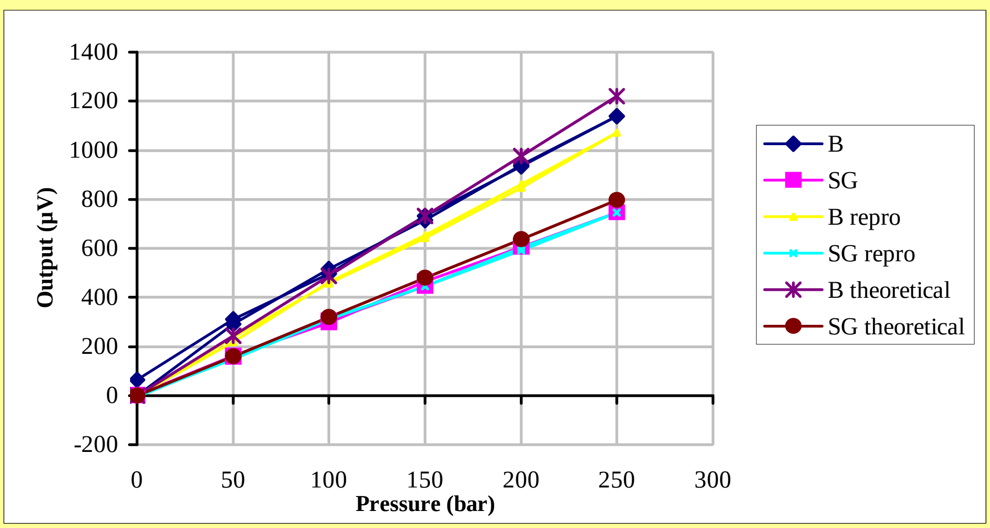


Figure 5-4: Strain gauges on OD=2mm tube set-up



B = Complete Wheatstone bridge
SG = One strain gage (¼-bridge)

Figure 5-5: Feasibility test, strain gauge calibration results on OD=2mm tube

6 Test procedure

Step	Action
1.	Perform He-leak test on test item prior to filling.
2.	Fill the system with CO_2
3.	Install the system into the climate chamber, including temperature sensors and power wires etc.
4.	Start data-acquisition system
5.	Set climate chamber and measurement section to 0 °C and accumulator to +5 °C
6.	Set climate chamber to –50 °C @ 5 °C/min
7.	Switch all zone heaters controls on to keep feed & return lines between –50 and –30 °C
8.	Wait for zone heater 1 temperature to become -30 °C
9.	Set measurement section to –120 °C @ 1.7 °C/min
10.	As soon as measurement section = -50 °C: Set climate chamber to –70 °C @ 0.4 °C/min
11.	After 30 minutes switch off zone heater 1
12.	After 30 minutes switch off zone heater 2
13.	After measurement section reaches –120°C wait until feed & return lines are –65 ° or lower
14.	Wait at least 1 hour
15.	Increase measurement section temperature with a maximum rate-of-change of 1.7 °C/min as long as tube section is elastic, simultaneously watch strain gauge outputs.
16.	If this is the third cycle AND the strain gauge outputs reproduced, further increase the measurement section temperature to +25 °C or until the tube bursts, whichever comes first.
17.	If this is the third cycle go to step 23
18.	Switch on zone heater 2, control zone temperature between –50 and –30 °C
19.	After 30 minutes switch on zone heater 1, control zone temperature between –50 and –30 °C
20.	After 30 minutes set climate chamber to –50 °C @ 5 °C/min
21.	Wait at least 1.5 hours
22.	Repeat from step 9, twice
23.	Set climate chamber to 10 °C @ 5 °C/min Set accu to +15 °C Set measurement section to +10 °C @ 5 °C/min

24.	Check CO_2 content in viewing glass
25.	Set climate chamber to 20 °C @ 5 °C/min Set accu to +20 °C Set measurement section to +20 °C @ 5 °C/min
26.	Remove test set-up and empty it
27.	Visual inspection

Table 6-1: Test procedure

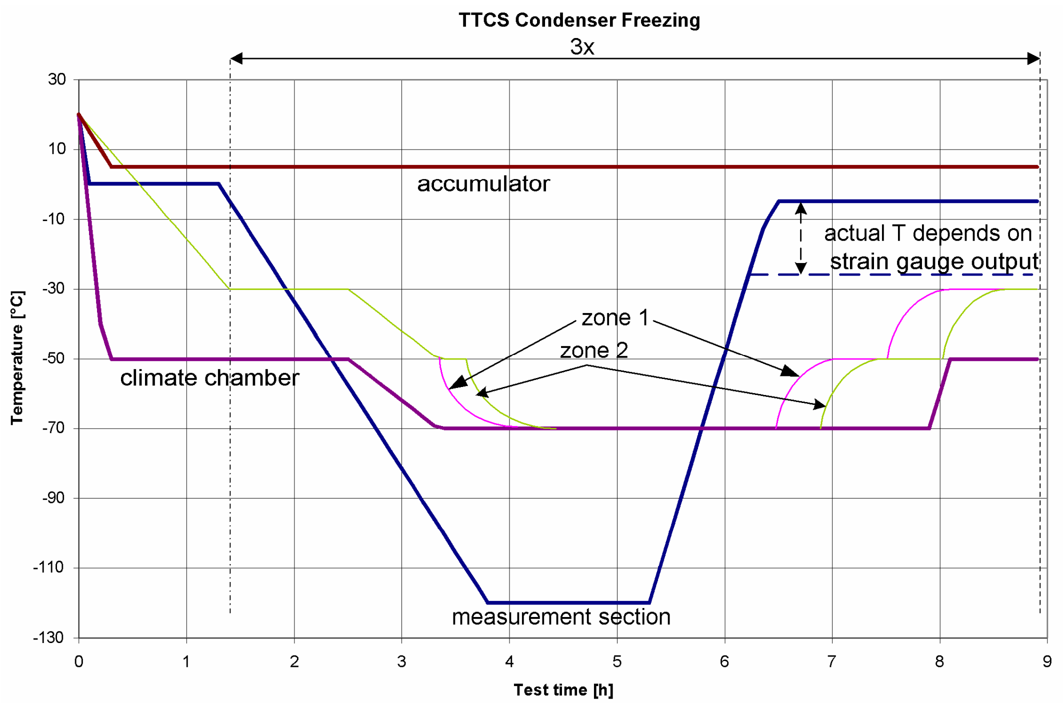


Figure 6-1: Measurement section freezing temperature cycle

7 Test result evaluation

Test results may roughly fall into one of the following three categories:

1) Pressure is higher than the CO_2 melting line

- In the very unlikely event this will happen, the measurement section is probably too weak to measure up to –5 °C, while feed & return lines are blocked by 'packed CO_2 ice'. If the test tube eventually is allowed to burst, a tube with known properties however will provide additional information. The MDP will be high, but not exactly known and probably too high for even the strongest materials on the market.

2) Pressure is equal to the CO_2 melting line

- The measurement section could be too weak to measure up to –5 °C, while feed & return lines are blocked by 'packed CO_2 ice'. If the test tube eventually is allowed to burst, a tube with known properties however will provide additional information. Secondly the freezing phenomenon is considered verified and the melting line can be used to determine the MDP.

3) Pressure is lower than the CO_2 melting line

- The measurement section is probably strong enough to measure up to –5 °C. The MDP can be directly derived from the strain gauge outputs.

8 Stress calculations on capillary tubing under high pressure

8.1 Material properties

For the material of the tube, Inconel 718 has been chosen due to its high yield and ultimate tensile stress. The material properties are listed in *Table 8-1* (Ref. [1] and [2]). Due to the large operational temperature range, differences in tensile and yield stress, modulus of elasticity and coefficient of thermal expansion can occur. For more details on this, one should Ref. [1] and [2] . For the current preliminary investigation the use of the values listed in *Table 8-1* are assumed to be sufficient accurate.

Density	8190 kg/m^3
Modulus of elasticity	200 Gpa
Yield stress	1034 MPa
Ultimate tensile stress	1280 MPa
Coefficient of thermal expansion	13.0 μm/m ^{o}C
Thermal conductivity	11.4 W/m ^{o}C
Specific heat	435 J/kg ^{o}C

Table 8-1: Material properties of Inconel 718

8.2 Internal pressure

If the wall thickness of the tube is more than about one-tenth of the radius, the radial and circumferential stresses cannot be considered uniform throughout the thickness of the wall and the radial stress cannot be considered to be negligible. Following formulas describe the stresses in the wall at the inside surface (where they have a maximum) (Ref. [3]):

Circumferential:

$$\sigma_t = p_i(\frac{r_o^2 + r_i^2}{r_o^2 - r_i^2}) \qquad (1)$$

Radial:

$$\sigma_r = -p_i \qquad (2)$$

Longitudinal:

$$\sigma_l = p_i(\frac{r_i^2}{r_o^2 - r_i^2}) \qquad (3)$$

The longitudinal stress is zero if the ends of the tube are open.
As a measure of the limiting stress, the Von Mises stress is taken. It is defined as (for $\sigma_l = 0$):

$$\sigma_{VM} = \sqrt{\sigma_r^2 + \sigma_t^2 - \sigma_r \sigma_t} \qquad (4)$$

Substituting the expressions for σ_r and σ_t yields:

$$\sigma_{VM} = p_i \sqrt{\alpha^2 + \alpha + 1} \qquad (5)$$

Where:

$$\alpha = \frac{r_o^2 + r_i^2}{r_o^2 - r_i^2} \qquad (6)$$

Note that the relation between radii and wall thickness is given by:

$$r_o = r_i + t \qquad (7)$$

Using a safety factor of 4.0 on the ultimate strength (which is the limiting value), the maximum allowable Von Misses stress becomes:

$$\sigma_{VM} = 0.25\sigma_u \qquad (8)$$

From the formulas it can be seen that the circumferential stress at the inner surface of the tube approaches the pressure p_i as the ratio of outer to inner pressure approaches infinity. It is apparent, therefore, that if the stress is to be limited to some specific value σ, the pressure must never exceed $p_i = \sigma$, no matter how thick the wall is made. For a given inner radius, the outer radius is calculated with Eq. (7) and factor α with Eq. (6). For a given value of the ultimate stress, equation (5) gives the explicit relation between the pressure and the wall thickness. This relation is plotted in *Figure 8-1* for two different inner radii. In *Table 8-2* and *Table 8-3* the used values are given.

Table 8-2 Allowable internal pressure for inner radius 0.5 mm

r_i [mm]	t [mm]	r_o [mm]	α [-]	Allowable pressure [bar]
0.5	0.5	1.0	1.6667	1371
0.5	1.0	1.5	1.2500	1639
0.5	1.5	2.0	1.1333	1731
0.5	2.0	2.5	1.0833	1773
0.5	2.5	3.0	1.0571	1796
0.5	4.5	5.0	1.0202	1829
0.5	5.0	5.5	1.0167	1832

Table 8-3 Allowable internal pressure for inner radius 1.0 mm

r_i [mm]	t [mm]	r_o [mm]	α [-]	Allowable pressure [bar]
1.0	0.5	1.5	2.6000	994
1.0	1.0	2.0	1.6667	1371
1.0	1.5	2.5	1.3810	1545
1.0	2.0	3.0	1.2500	1639
1.0	2.5	3.5	1.1778	1695
1.0	4.5	5.5	1.0684	1786
1.0	5.0	6.0	1.0571	1796

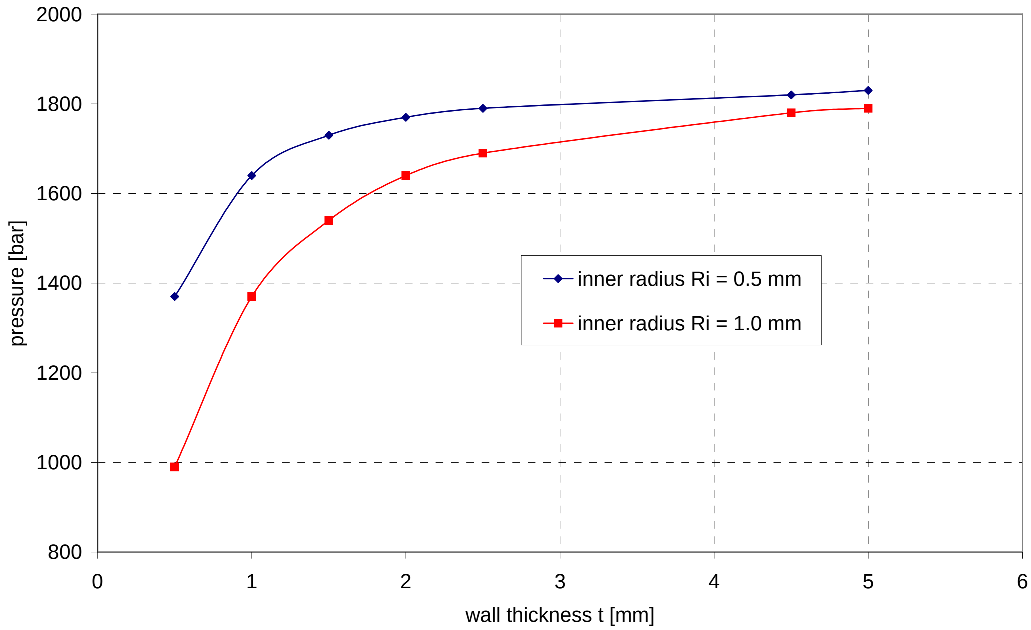


Figure 8-1: Allowable internal pressure as function of the wall thickness for two different values of the inner radius. The limiting stress is the Von Mises stress, with a safety factor of 4.0 on the ultimate tensile stress (i.e. $\sigma_{VM} < 0.25\ \sigma_u$)

In *Figure 8-2* to *Figure 8-8* relations between wall thickness and Von Mises stress is shown for different values of internal radius and internal pressure. These formulas are valid if the Von Mises stress is lower than the yield stress of the material. Note that the relations are independent of the material properties of the tube, but only on geometrical properties. The relations can therefore be used for different tube materials. The values used for constructing Figure 8-2 are listed in *Table 8-4*.

Table 8-4: Von Mises stress as function of wall thickness for internal pressure 1000 bar and different values of the inner radius.

	r_i =0.5 [mm]	r_i =1.0 [mm]	r_i =1.5 [mm]
t	Von Mises	Von Mises	Von Mises
0.5	233.3	321.9	416.3
1	195.3	233.3	276.4
1.5	184.9	207.1	233.3
2	180.5	195.3	213.4
2.5	178.2	188.8	202.2
4.5	175	179.2	184.9
5	174.7	178.2	183

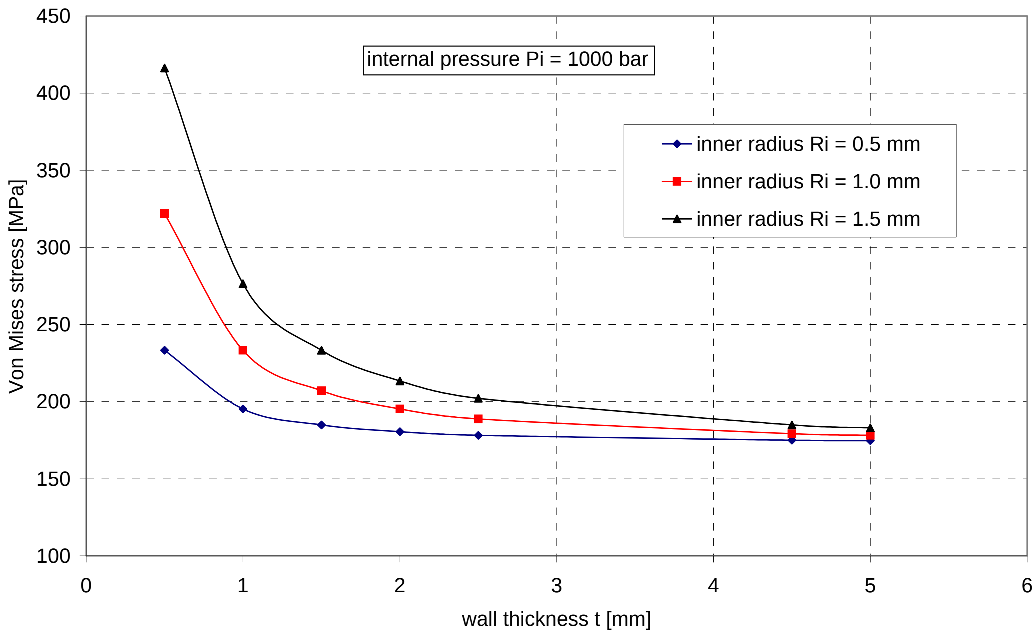


Figure 8-2 Von Mises stress as function of the wall thickness for different values of the inner radius for inner pressure of 1000 bar

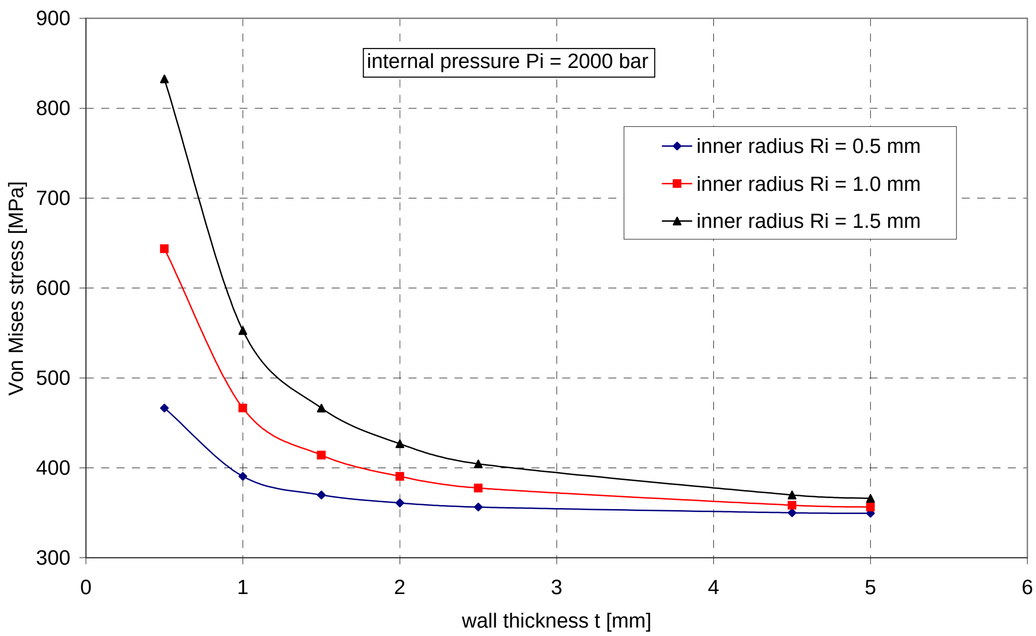


Figure 8-3 Von Mises stress as function of the wall thickness for different values of the inner radius for inner pressure of 2000 bar

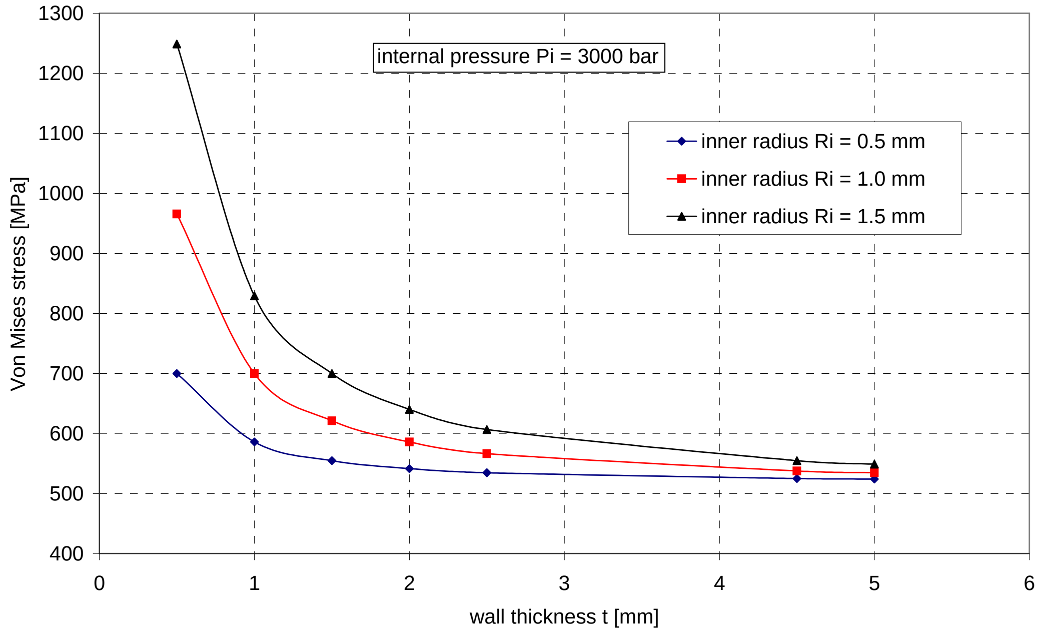


Figure 8-4: Von Mises stress as function of the wall thickness for different values of the inner radius for inner pressure of 3000 bar

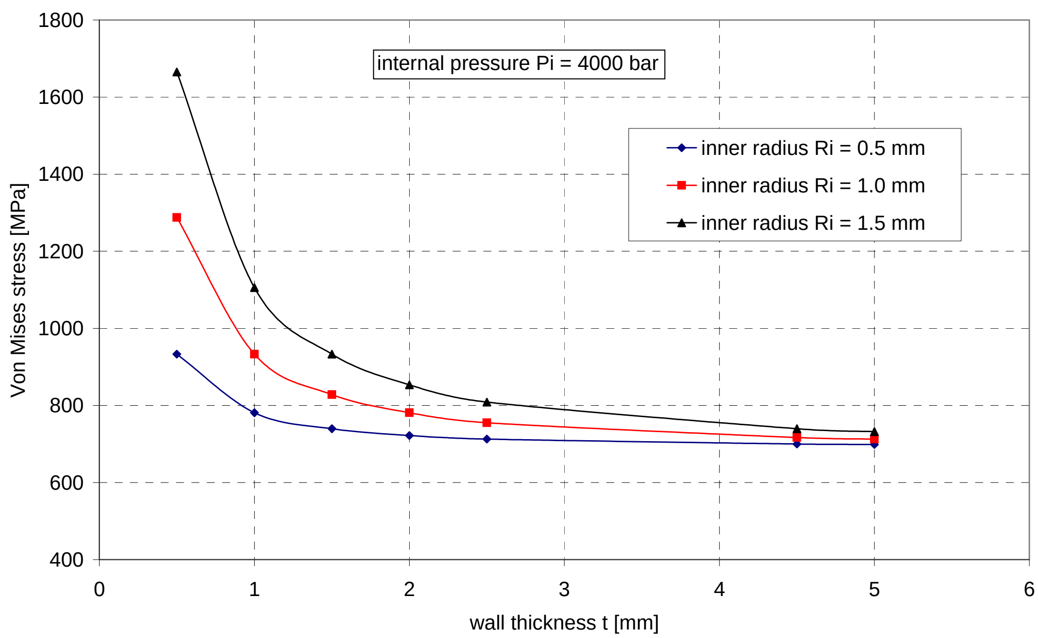


Figure 8-5: Von Mises stress as function of the wall thickness for different values of the inner radius for inner pressure of 4000 bar

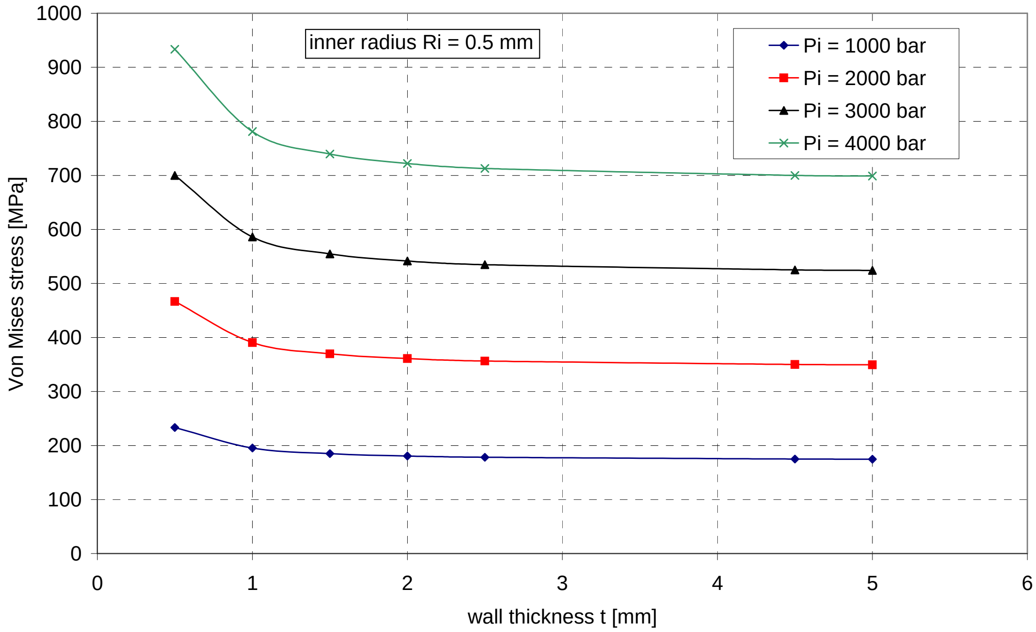


Figure 8-6: Von Mises stress as function of the wall thickness for different values of the inner pressure for inner radius of 0.5 mm

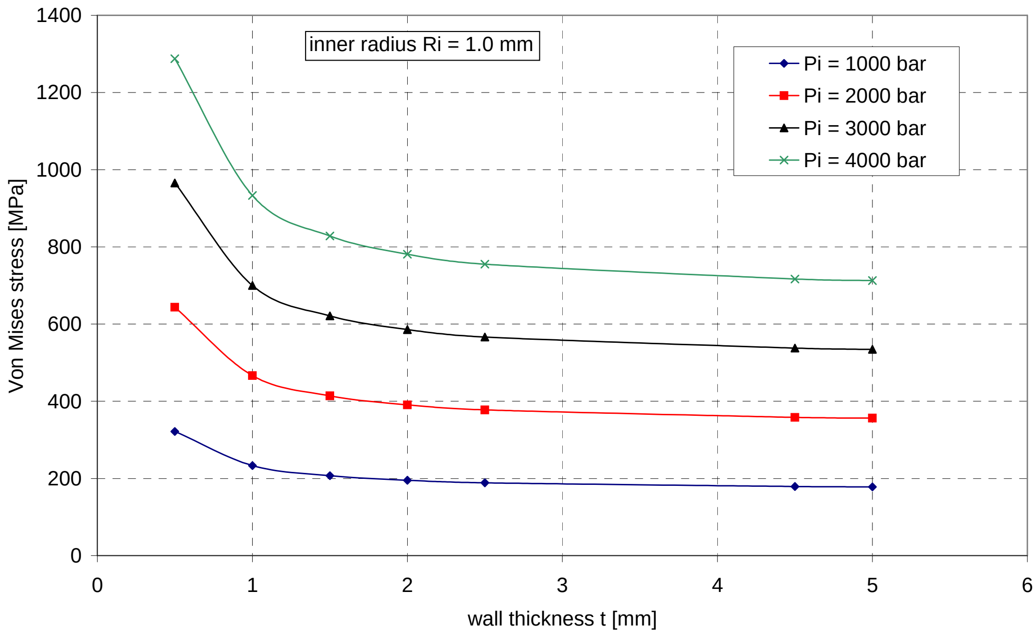


Figure 8-7: Von Mises stress as function of the wall thickness for different values of the inner pressure for inner radius of 1.0 mm

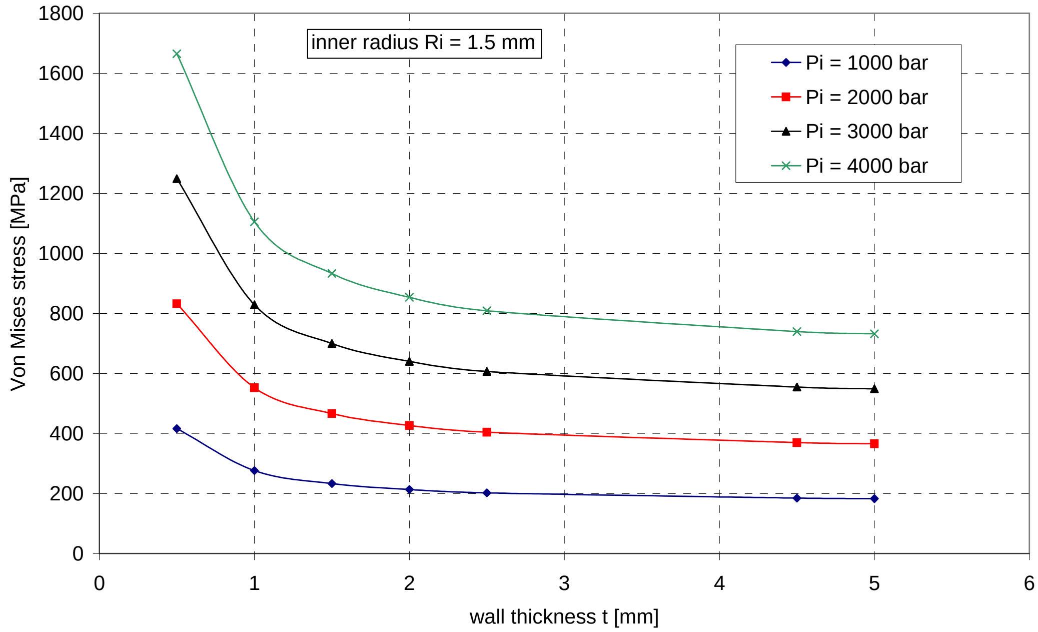


Figure 8-8: Von Mises stress as function of the wall thickness for different values of the inner pressure for inner radius of 1.5 mm

With a factor of safety of 4 on the ultimate stress (Figure 8-1), it seems to be that the internal pressure can never be higher than 1800 bar. However, the situation looks worse than it actually is (Ref. [3]): as a thick walled cylinder is pressurised, the bore material, which is the most highly stressed part of the cylinder, begins to yield. With further increase of the pressure the yield surface begins to propagate. At some stage, when more and more of the cylinder is entering the plastic regime, the bore material starts to strain hardening. When the pressure is removed, it leaves residual compression in the inner part and residual tension in the outer part. Therefore the cylinder can withstand higher pressures than would follow from the standard pressure vessel formulas, which are in fact only valid for isotropic material, resulting in conservative estimates of the wall thickness necessary to withstand high pressures.

The technique of applying a high initial pressure is frequently used in the manufacturing of gun barrels and cannons and is called autofrettage (Ref. [3]).
The expression for the bursting pressure, p_u , is a function of the ultimate tensile strength and the radii of the tube:

$$p_u = 2\sigma_u \frac{r_o - r_i}{r_o + r_i} \qquad (9)$$

commonly known as the mean diameter formula, is essentially empirical but agrees reasonably well with experiments for both thin and thick cylindrical tubes. For very thick tubes the formula:

$$p_u = \sigma_u \ln \frac{r_o}{r_i} \qquad (10)$$

is preferable. Greater accuracy can be obtained by using with this formula a multiplying factor that takes into account the strain hardening properties of the material:

$$p_u = \frac{2\sigma_y}{\sqrt{3}}(2 - \frac{\sigma_y}{\sigma_u}) \ln \frac{r_o}{r_i} \qquad (11)$$

In the above expressions the ultimate stress and yield stress are used without safety factor. A safety factor can be applied to the bursting pressure. Using FS = 4 for the ultimate tensile stress, the bursting pressure has to be divided by 4. The result of the different formulas is displayed in Figure 8-9. With a maximum allowable internal pressure of, for example, 4500 bar (= 450 MPa), the wall thickness varies from 1.2 to 2.4 mm, depending on the formula used. Note that using the standard tube formulas, no wall thickness would be able to withstand this pressure.

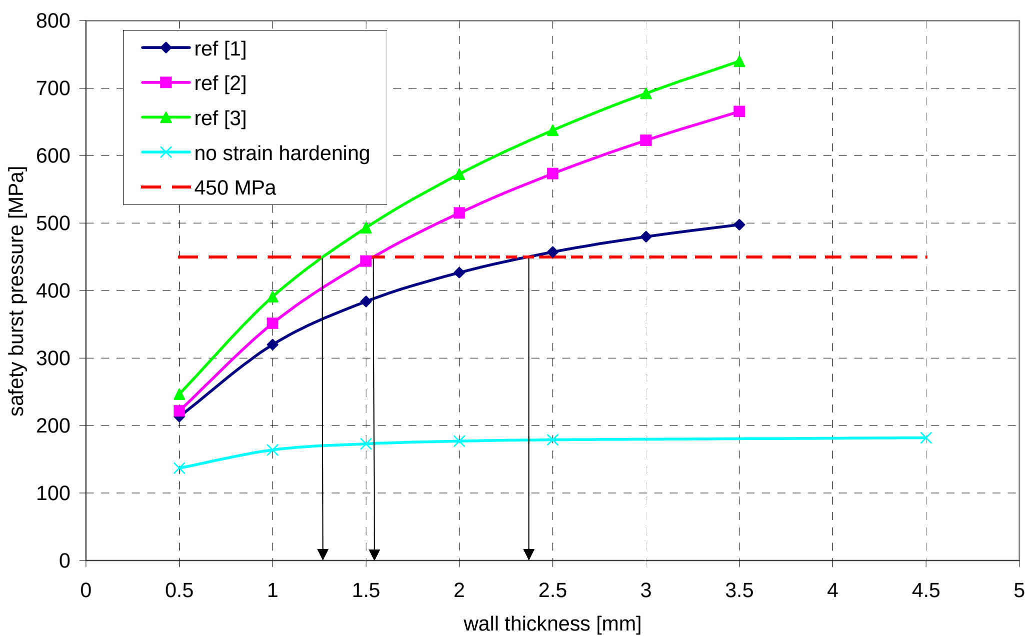


Figure 8-9: Safety burst pressure as function of the wall thickness, using a safety factor of 4 on the burst pressure (for Inconel 718)

The results without using a safety factor are displayed in *Figure 8-10*. Very high pressures can be achieved before the tube actually bursts.

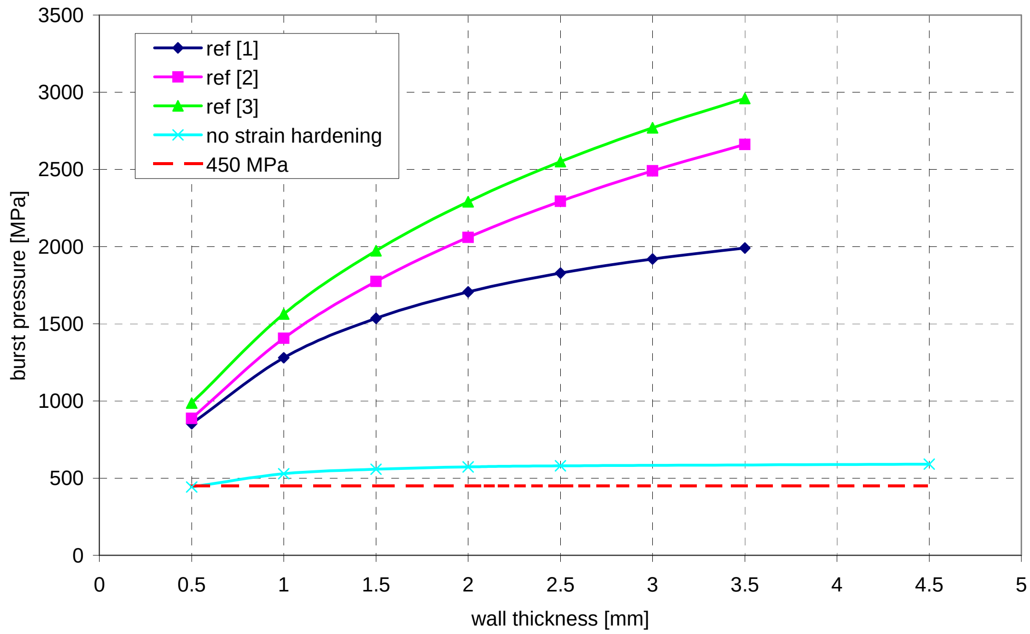


Figure 8-10: Burst pressure as function of the wall thickness, without a safety factor on the burst pressure (for Inconel 718)

Note that the results are dependent on the material properties: for stainless steel with a lower yield stress and ultimate tensile stress, the maximum burst pressures will be lower. To achieve for instance a pressure of 4500 bar, the wall thickness would increase.

8.3 Thermal expansion

The way of attachment of Inconel to aluminium is currently under investigation. Two principally different techniques are currently considered, both having their (dis)advantages:

1. solder the tubing, which causes stresses in all materials as their thermal expansion differ
2. apply highly flexible epoxy [Appendix A, possible candidate], which causes major stresses in the epoxy.

The calculations below focuses on a strong mechanical connection between the two materials (soldering).

The base plate is made of aluminium which has a thermal expansion coefficient of α_{al} = 23 μm/m ^{o}C, which is almost twice as much as for Inconel 718. Considering the temperature range

–120 °C (lowest condenser temp) to +200 °C (approximate soldering manufacturing temp), this will introduce large thermal stresses.
With a simple calculation the effect of temperature on the stresses can be roughly estimated. For this, assume two pieces of material are fixed together at their ends, and both having a cross area of $A_{al} = A_{in} = 1\ mm^2$, then the axial force can be derived from:

$$P = \frac{E_{al} A_{al} E_{in} A_{in}}{E_{al} A_{al} + E_{in} A_{in}} (\alpha_{al} - \alpha_{in}) \Delta T$$

where E_{al} = 70 GPa and ΔT = 320 °C. The values for Inconel can be found in *Table 8-1*.
Then the axial force is 160 MN and the axial stress is 160 MPa, which is both lower than the yield stress (range 270 to 480 MPa, depending on the alloy used) and the ultimate tensile stress of aluminium (range 300 to 550 MPa). A more detailed thermal analysis of the structure is necessary to investigate if this high thermal stress can occur in the corners of the tube.

8.4 Conclusions

- Allowable internal pressures can be higher than the values found from standard pressure vessel formulas due to strain-hardening of the tube material.

- Thermal stress can be severe but values are expected to be lower than the yield stress of aluminium. A more detailed analysis will be necessary to detect possible problem areas and to find solutions for this.

9 References

[1] Bibus Metals: Datasheet Inconel Alloy 718. W.Nr. 2.4668.
[2] Allvac: Technical data sheet Allvac 718 Alloy
[3] Young, Warren C. (1989): Roark’s Formulas for Stress and Strain. 6th Edition. McGraw Hill Book Company.

Appendix A: Technical Data Sheet Epoxy EP21TDC-2LO

MASTER BOND POLYMER SYSTEM EP21TDC-2LO

Two Component, Low Outgassing Epoxy Resin Compound Featuring Flexibility and Thermal Conductivity For High Performance Bonding, Sealing, Coating, And Encapsulation. Cryogenically Servicable

Product Description

Master Bond Polymer System EP21TDC-2LO is a low outgassing two component highly flexible, thermally conductive epoxy resin compound for high performance bonding sealing, coating, and encapsulation. It is formulated to cure fully at ambient temperature or more quickly at elevated temperature with a convenient one to three mix ratio by weight. The cured compound exhibits high elongation and excellent toughness. As very little exotherm is developed during cure the Master Bond EP21TDC-2LO is suitable for potting and encapsulating thick as well as thin sectioned configurations. This epoxy resin compound exhibits superior tensile shear and peel strength for bonding and sealing applications. It adheres well to many different substrates including metals, glass, ceramics, rubber and plastics. The hardened composition is an excellent electrical insulator with outstanding resistance to chemicals including water, acids, bases and salts. The service temperature range is from 4°K to 250°F making it suitable for many cryogenic applications. Master Bond EP21TDC-2LO is widely used in the electronic, electrical, optical, fiberoptic, aerospace and other industries where low outgassing, flexibility, and thermal conductivity are desirable.

Product Advantages

- Convenient mixing: non critical one to three weight ratio
- Easy application: product spreads evenly and smoothly
- Versatile cure schedules: ambient temperature cures or fast elevated temperature cures as required
- High peel strength and elongation, excellent thermal shock and chemical resistance
- Superior bonding properties on similar and dissimilar substrates, superb impact resistance
- Excellent durability, high thermal conductivity combined with good electrical insulation properties.
- 100% reactive, no solvents, dilutes or volatiles emitted during cure or in service
- Cryogenically serviceable; temperature range 4K-2 50°F.
- Meets NASA low outgassing specifications.

Product Properties

- Mixing ratio, weight or volume, parts A to B 1/3
- Viscosity of mixed adhesive, 75°F, cps ....paste
- Working life after mixing, 75°F, 100 gm mass, minu tes ....>90
- Cure schedule ambient temperatures, 75°F hrs ....48-72 hours
- Cure schedule ambient temperatures, 150°F hrs ....3-4 hours
- Tensile strength, psi, 75°F pli 1070
- Elongation, 75°F ....>50
- Tensile shear strength, aluminum/aluminum, 75°F, p si ....>980
- T-peel strength, 75°F pli ....>15
- Hardness, shore D 36
- Water vapor permeability, gms/m2/24 hours ....<0.5
- Moisture vapor transmission, gm/m2/24 hours ....<0.5
- Volume resistivity, 75°F ohm cm ....$>10^{12}$
- Thermal conductivity, BTU * in/ft^2 * hr * °F 9
- Thermal expansion coefficient, in/in x10^{-6}°C..........90-100
- Service temperature range, ...4K to 250°F
- Shelf Life, unopened containers @ RT 75°F..........6 months

Appendix A: Technical Data Sheet Epoxy EP21TDC-2LO, cont'd

Preparation of Compound for Casting or Bonding

Master Bond Polymer System EP21TDC-2LO is prepared for use by thoroughly mixing part A with part B in a one-to-three mix ratio by weight. Mixing should be done slowly to avoid entrapping air, stir until uniform. The working life of a 100 gm batch is in the order of 90 minutes. It can be substantially lengthened by using shallower mixing vessels or mixing smaller size batches. For bonding and sealing uses, matching surfaces should be carefully cleaned, degreased and dried to maximize bond strength. When bonding to metal surfaces, chemical etching should be employed when the bonded joints are to exhibit optimal environmental durability. Non-porous surfaces should be roughened with sandpaper or emery paper and solvent cleaned using acetone or xylene.

Compound Application and Assembly

Master Bond Polymer System EP21TDC-2LO can be conveniently cast or applied with a spatula, knife, trowel, etc. When bonding, enough (mixed) adhesive should be applied to obtain a final adhesive bond line thickness of 4-6 mils. This can be accomplished by coating each surface with an adhesive film of 2-3 mils thick. Porous surfaces may require somewhat more adhesive to fill the voids than non-porous ones. Thicker glue lines do not increase the strength of a joint but do not necessarily give inferior results as the EP21TDC-2LO compound does not contain any volatiles. The parts to be bonded should then be pressed together with just enough pressure to obtain and maintain intimate contact during cure.

Cure

Master Bond Polymer System EP21TDC-2LO can be cured at room temperature or at elevated temperatures as desired. At room temperature Master Bond Polymer System EP21TDC-2LO will cure in 2-3 days. Faster Cures can be realized at elevated temperatures, e.g. 3-4 hours at 150°F. Remove excess material promptly with a spatula before it hardens. Then wipe with rag and solvent such as isopropyl alcohol, toluene or acetone. Thinner sections of epoxy take longer to cure than thicker ones.

Handling and Storage

All epoxy resins should be used with good ventilation and skin contact should be minimized. The EP21TDC-2LO compound employs a low toxicity hardener. To remove resin or hardener from skin, use solvent, then wash with mild soap and water. If material enters the eyes, flood with water and consult a physician. Optimum storage is at or below 75°F in closed containers. No special storage conditions are necessary. Containers should however be kept closed when not in use to avoid contamination. Cleanup of spills and equipment can be achieved using acetone or xylene employing proper precautions of ventilation and flammability.